Smart Structural Health Monitoring and Evacuation system

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Abstract. As much as air quality, ventilation, lighting, etc. inside a building are important, the health of the building is also a vital concern. It's really important to detect the damages in a building in advance to prevent hazardous and life-threatening accidents. It is also important to evacuate people to safety during the times of emergency, for example in the case of fire. Currently, in many of the commercial buildings, few brave employees take up the task of evacuating people inside the building to safety, before themselves. To address these concerns, we propose a smart structural health monitoring and evacuation system that monitors the structural health of a non-residential building and evacuates people to safety without any human intervention at the time of emergency.

Keywords: Structural Health Monitoring (SHM) · Smart Evacuation (SC).

1 System Introduction

According to data collected by *National Crime Records Bureau* (NCRB), India, 38363 people lost their lives due to the collapse of various structures between 2001 and 2015 [2]. One more interestingly shocking stat is provided by encore fire protection (US-based) company blog which says that between 2004 and 2013, nonresidential building fires killed 65 people, injured 1,425, and created $2,461,400,000 in damage [3]. These stats prove that there is a need for a smart diagnosis system that looks for structural damages in the building and also in times of emergency it guides people to safety. We propose to call this system - smart health monitoring and evacuation system.

Our system intends to monitor physical as well as geometrical deformations in a building using various sensors and send live data to the concerned party. At the time of emergency depending upon the density of people inside the building, using an optimization algorithm and the building plan, our system guides people to the nearest exit points. Our system incorporates automatic operation of evacuation chute as well.

To elaborate on the SHM part, our system uses surface-mounted piezoelectric (PZT) patches (which acts both as a high-frequency transmitter as well as a sensor) on the internal walls of the building and ceiling, to detect physical deformations like cracks, blemishes, etc. Based on the insights given by [4], one of the PZT patches transmits the high-frequency waves, and the rest of the PZT patches act as sensors, where the sensor output decreases depending on the severity and number of cracks. Gyro sensor used by the SHM system along with a camera detect and localize geometrical deformation and orientation of the building. Now about the SE system, our system uses different colored lights and voice assistance to guide people to safety.

2 System Analysis

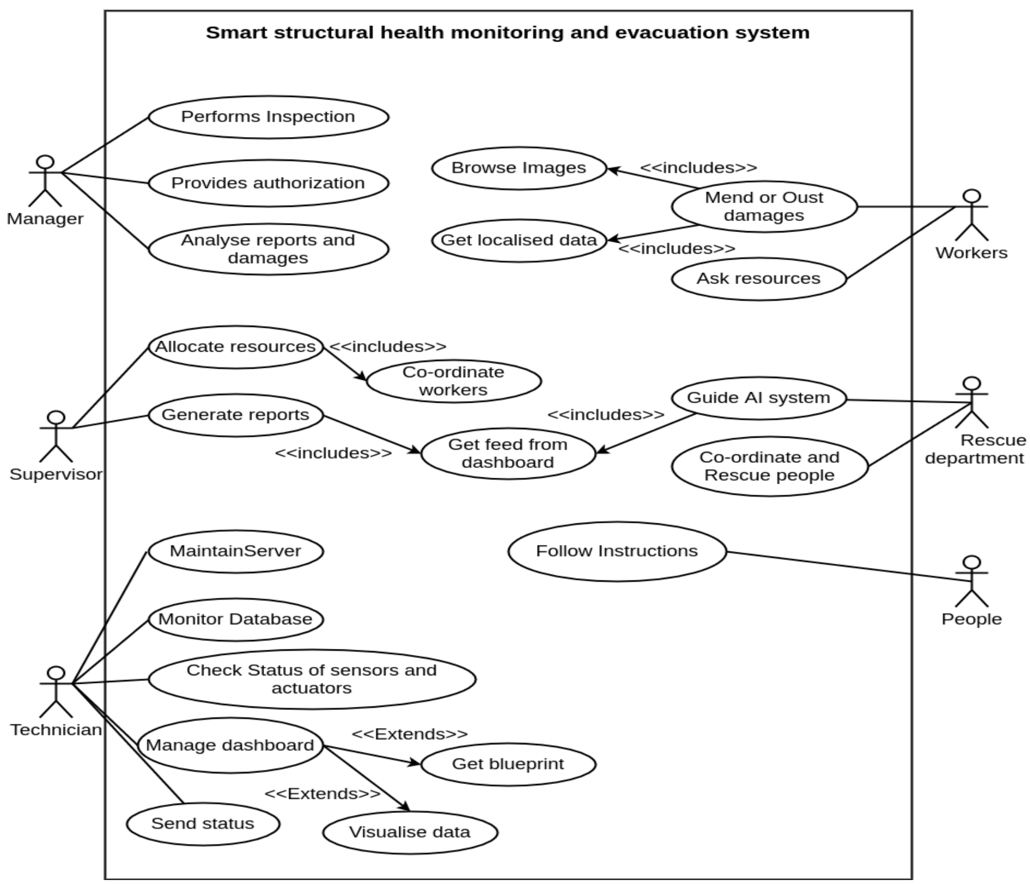

Fig. 1. Use case diagram of Smart health monitoring and evacuation system

The system analysis includes six actors according to various levels of authority. The manager has the highest authority and he can perform inspections and analyses by providing authorization. The Supervisor of the system in-turn allocates resources and manages workers. The technician regulates the interface between the hardware and the software components and manages the dashboard. Workers are responsible for correcting structural damages. The Rescue department regulates the people and protocols to be followed in case of any emergency. The goal is to help people to follow the instructions correctly and guide them to safety.

3 System Architecture Design

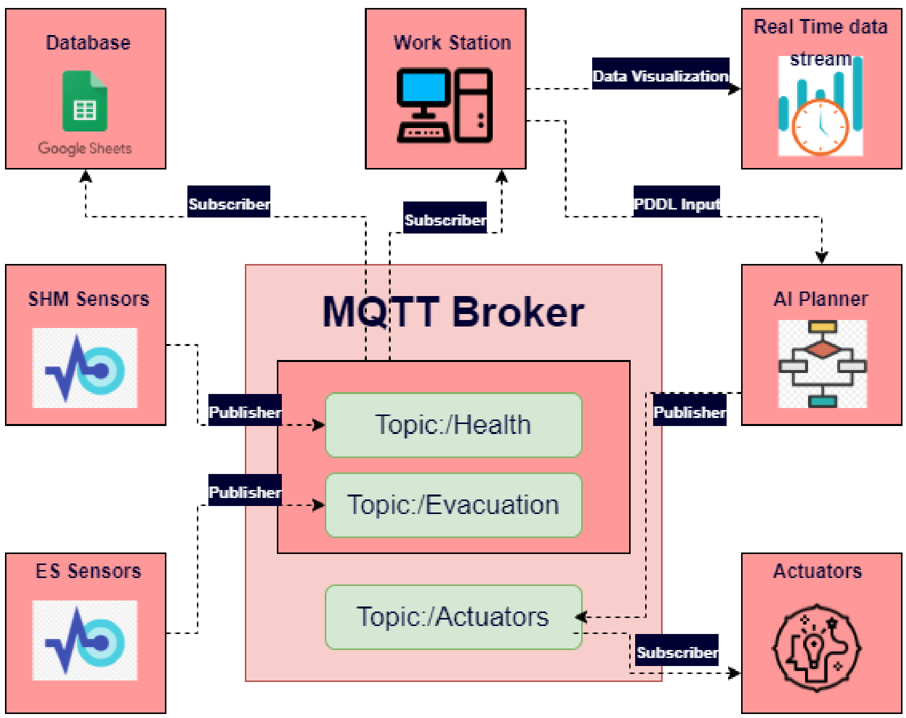

Fig. 2. Architecture of the Smart health monitoring and evacuation system

As discussed earliar, our system is divided into two sub systems - Structural Health Monitoring system (SHM) and Evacuation system (ES). Both the sub systems work independently. Please refer to the architecture diagram given in Fig. 2.

SHM has a server running in Raspberry pi (RPI) listening to data from various sensors and writing that data to Google sheets. Once a month, a detailed report is sent to the authority. Also our SHM sends data to a mqtt server that creates the end file for the data visualization dashboard. Detailed explanation is given in section 4.

ES is a event based application running in RPI that waits for flame sensor's input and executes the evacuation sequence explained in detail in section 4. ES also logs data to the Google sheets.

4 System Implementation

In this section, first we explain the set up for SHM and ES and then comes the implementation, data processing, AI planning and visualization part. A list of sensors used by our System and the sub systems (SHM and ES) are given in Table 1.

Table 1. List of sensors and their applications

Sensors	**System**	**Application**
Piezoelectric sensor	SHM	For detecting vibration signals sent by the transmitter.
Gyro sensor	SHM	For detecting any detect motion or displacement of the building structure in x, y and z directions.
Moisture sensor	SHM	For detecting the water retention in building structure that looks out for any kind of structural damage due to seepage.
Camera	SHM	For capturing images of the outer wall for crack detection using image processing.
Smoke sensor	ES	For detecting the smoke.
Flame Sensor	ES	For detecting the flame.
Proximity sensor	ES	For checking the human presence in order to control the opening and the closing of evacuation chute for evacuating people during the time of emergency.

- **Setup for SHM:**
  For SHM we have taken a symbolic representation of a wall containing a crack. We have used one ceramic piezoelectric plate as a transmitter and two as sensors. we have placed transmitter on one side of the crack, one sensor (lets call it sensor 1) on the other side of the crack and a second sensor (lets call it sensor 2) on the same side of the transmitter but at a certain distance. The transmitter is connected to the RPI that generates a PWM signal at a frequency above 20KHz. The sensors are connected to esp32 which sends the data wirelessly to RPI over TCP/IP. It is expected that the output of the sensor 1 is less than sensor 2. For checking the seepage in the walls due to water logging, we are using moisture sensor.
  We have used gyroscope service from TI's (Texas Instrument) BLE sensortag. The sensortag is mounted on the wall which senses the displacement of the wall. Sensortag is connected to the RPI over bluetooth.

We have used a camera compatible with RPI. RPI uses this camera to take pictures of the wall and detect cracks in the image. If there are any, RPI uploads data in .csv format to Google drive.

- **Setup for ES:**
  ES is an event based application that waits on flame sensor event, it also checks data from gas sensor and triggers a python script that runs the evacuation algorithm in anylogic modelling and simulation tool. The tool needs a floor plan to show the simulation, for that we have provided a floor plan of one of our university floor. Sometimes,there are some areas in the floor which are far from the emergency exit, in that case many buildings use chute to evacuate people. The chute is dropped from one of the windows. We are using motor to represent the automatic operation of the chute. Our ES system also actuates buzzer (depicting alarm sound) and led light. Table 2 shows the list of actuators that we are using.

Table 2. List of actuators and their purpose.

Actuator	**Purpose of the actuator**
Buzzer	To indicate fire.
Motor	To indicate the opening and closing of the evacuation chute.
Led Light	To indicate the warning lights.

- **Implementation:**
  Find implementation details of structural health monitoring : Click here
  1. **Message Queuing:** Pubsub (publish - subscribe) messaging with MQTT (Message Queuing Telemetry Protocol). Readings from sensors in SHM system are published to MQTT topic named 'health' and readings from sensors in ES are published to MQTT topic named 'evacuation'. MQTT broker after receiving the data, provides it for visualization and to the AI planner. Once the AI planner has the decision made, provides it to the MQTT broker which in turn drives the actuators given in Table 2.
  2. **Data Processing:** All the sensor readings are stored in google sheets and once a month a detailed report is sent to the authorized person.
  3. **AI planning:** The processed data is subjected to AI planning by using the PDDL planner [1]. There are two goals, one, to monitor health and second, to send alerts in case of emergency, are achieved using the tool. When the health monitoring sensors has a change in value the PDDL solver sends messages to the system and triggers a soft actuation of sending email (soft acutation).The notify-emergency message is published when there is an abnormality in health monitoring data.
  4. **Data Visualization:** We are using matplotlib and animate (python libraries) for data visualization of live time series data acquired by a subscriber listening to the topics where sensor data is being published.

5 Discussion and Conclusion

Thr project Structural health monitoring and evacuation is done by evaluating the data published by sensors (gyro, camera, gas,flame, motion, piezo) to Raspberry pi using MQTT publish and subscribe methods. Outcome of the project helps in monitoring the status of structural integrity of the building, and warns the administrator of the building to evaluate the health of the building.

The system can be extended to make improvements like using high quality cameras to detect structural orientation over the period of time and human occupancy. It helps to integrate emergency evacuation routes display to the users. Data from the sensors can be used to inform the maintenance teams for repair and maintenance.

References

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All links were last followed on April 17, 2020.